5/27/21

14.1 : Multivariable Functions

MATH-323

Space curve: $\vec{r}: I \to \mathbb{R}^n$

Def: A multivariable function (of real input and a real output) is a function $f: D \subseteq \mathbb{R}^n \to \mathbb{R}$

f ↑ function's name; D ↑ domain; $\mathbb{R}$ ↑ codomain

$\text{dom}(f) = D$ in this notation

$\text{ran}(f) = \{ f(\vec{x}) : x \in \text{dom}(f)$

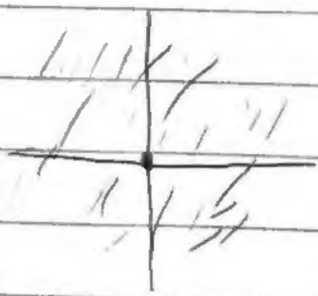
NB: If no domain is specified, we assume the biggest possible domain i.e. the "natural domain"

Ex: $f(x,y) = \dfrac{x^2 - y^2}{x^2 + y^2}$

in this case, $\text{dom}(f) = \{ (x,y) \in \mathbb{R}^2 : \dfrac{x^2-y^2}{x^2+y^2} \text{ is defined} \}$

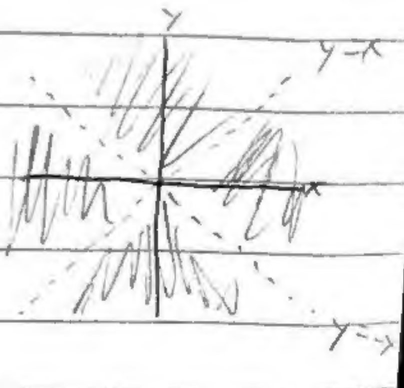
$= \{ (x,y) \in \mathbb{R}^2 : x^2 + y^2 \neq 0$

$= \{ (x,y) \in \mathbb{R}^2 : (x,y) \neq (0,0)$



Ex: $f(x,y) = \dfrac{\sin(x^2+y^2)}{x^2+y^2}$ has the same domain

Ex: $f(x,y) = \dfrac{x+y+1}{x^2-y^2}$

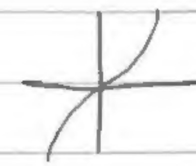


$\text{dom}(f) = \{ (x,y) \in \mathbb{R}^2 : x^2 - y^2 \neq 0 \}$

$= \{ (x,y) \in \mathbb{R}^2 : |x| \neq |y|$

Def: the graph of a function $f: D \subseteq \mathbb{R}^n \to \mathbb{R}$ is
graph$(f) = \{(\vec{x}, f(\vec{x})) : \vec{x} \in \text{dom}(f)\}$

Ex (from Calc I) $f(x) = x^3$



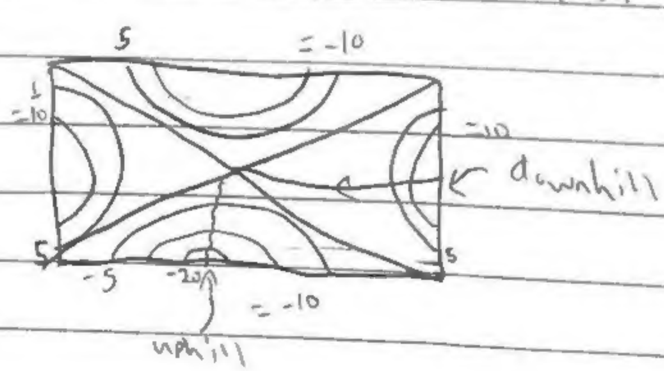
If $n=2$, this becomes
graph$(f) = \{(x,y, f(x,y)) : x \in \text{dom}(f)\}$
i.e. This is a picture of $z = f(x,y)$'s solution set

Ex: What does graph(f) look like for
$f(x,y) = \sqrt{x^2+y^2+1}$

Sol: $z = f(x,y)$
i.e. $z = \sqrt{x^2+y^2+1}$
i.e. $z^2 = x^2+y^2+1$ (for $z \geq 0$)
i.e. $-x^2-y^2+z^2 = 1$
so the graph of this f is one of the sheets of this 2-sheet hyperboloid

Q: How do we represent graph(f) for a 2-variable function?
A: Draw a contour map (or elevation map or level curves)

Picture:



Ex: in 4-dimensions: The hypersphere

$S^3 = \{\vec{x} \in R^4 : |\vec{x}| = 1$

(x, y, z, w) $\qquad |w| \le 1$

once $w = k$ is fixed $\qquad \sqrt{x^2 + y^2 + \cancel{z}^2 + k^2} = 1$

$$x^2 + y^2 + z^2 = 1 - k^2$$

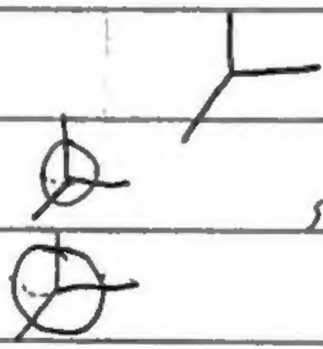
sphere of radius $\sqrt{1-k^2}$ about origin

we get thus a movie describing the hypersphere:
("w = time")

$w = -1$

$w = -\frac{1}{2}$ small sphere

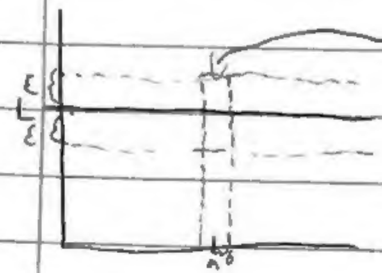
$w = 0$ bigger



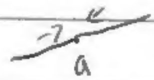
14.2 : Limits and Continuity of Multivariable Functions

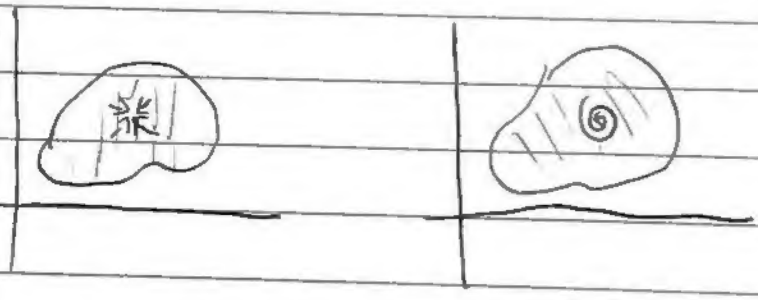
In Calc III, the formal definition of a limit goes like so:

<u>Def</u>: Let f be a multivariable function and let $\vec{a} \in \mathbb{R}^n$ be a limit point of the domain of f. The limit of f as $\vec{x}$ tends to $\vec{a}$ is $L \in \mathbb{R}$ when (for all unit vectors $\vec{u} \in \mathbb{R}^n$
For all $\varepsilon > 0$ there is a $\delta > 0$ for all $\vec{x} \in dom(f)$
we have $\|\vec{x} - \vec{a}\| < \delta$ $\quad |f(\vec{x}) - L| < \varepsilon$



all of $f(x)$ lives in that rectangle near a





<u>NB</u>: This definition is hard to use... In practice, we'll want to use the following proposition in its place: (multivariable version of "one-sided" limits)

<u>Prop</u>: (Curves Criterium for Limits): suppose f is a multivariable function and $\vec{a}$ is a limit point of its domain
$\lim_{\vec{x} \to \vec{a}} f(\vec{x}) = L$ iff for all space curves $\vec{r}(t)$ in $dom(f)$ such that $\lim_{t \to t_0} \vec{r}(t) = \vec{a}$ we have $\lim_{t \to t_0} f(\vec{r}(t)) = L$

<u>Notation</u>: $\lim_{\vec{x} \to \vec{a}} f(\vec{x}) = L$ | <u>Alt</u>: $f(\vec{x}) \to L$ as $\vec{x} \to \vec{a}$

Ex show that $\lim_{(x,y)\to(0,0)} \frac{x^2-y^2}{x^2+y^2}$ does not exist

Sol: Consider the collection $L_{a,b}(t) = \langle at, bt \rangle$
where $(a,b) \neq (0,0)$ of
Observe $\lim_{t\to 0} \ell_{a,b}(t) = \langle 0, 0 \rangle$

For $f(x,y) = \frac{x^2-y^2}{x^2+y^2}$, we know $f(\ell_{a,b}(t)) = f(at, bt)$

$$= \frac{at^2 - bt^2}{at^2+bt^2}$$

$$= \frac{a^2-b^2}{a^2+b^2}$$

$\therefore$ if it exists we have
$\lim_{t\to 0} f(\ell_{a,b}(t)) = L$ for all a, b
$\lim_{t\to 0} f(\ell_{a,b}(t)) = \lim_{t\to 0} \frac{a^2-b^2}{a^2+b^2} = \frac{a^2-b^2}{a^2+b^2}$

but if $a=1$, $b=0$ we would have $L=1$
and if $a=1=b$ we would have $L=0$